Neutron spin structure from e-^{3}He with Double spectator tagging at EIC

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2nd Precision Studies on QCD at EIC

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In collaboration with I. Ivica, J. R. Pybus, A. Jentsch, E. P. Segarra, M. D. Baker, O. Hen, D. Higinbotham, R. Milner, Z. Tu, A. Tadepalli, J. Rittenhouse West

Spin Puzzle

Gluon spin

Quark and Gluon internal motion

Quark Spin

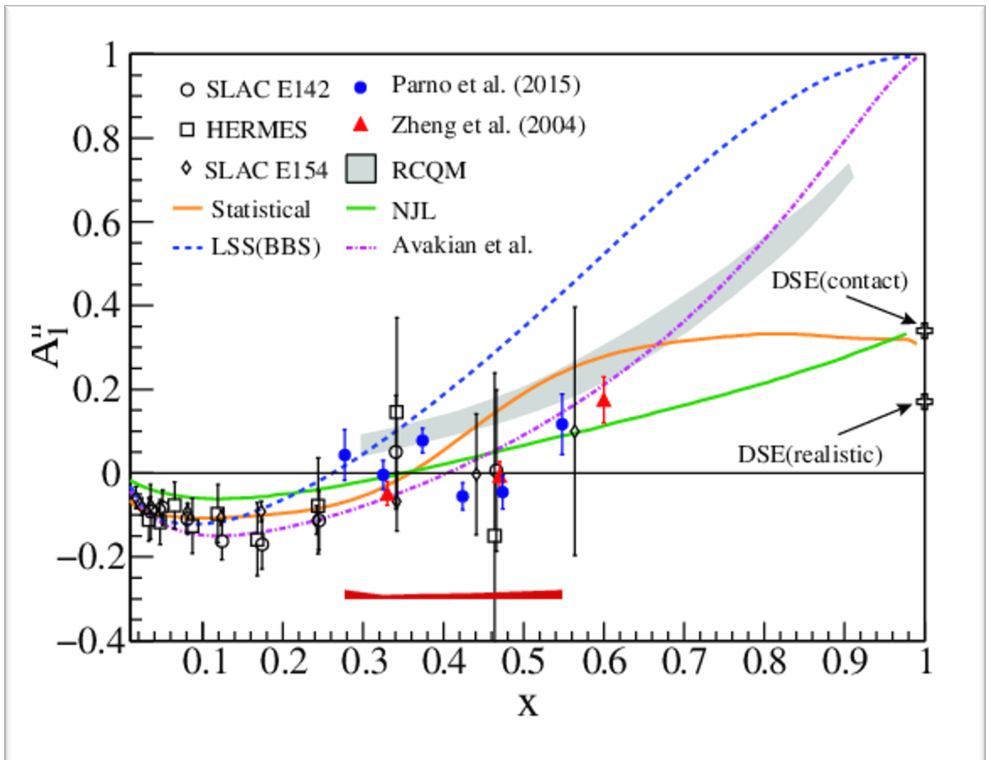
$$S_z^N = S_z^q + L_z^q + J_z^g = \frac{1}{2}$$

Spin Puzzle

$$g_1(x,Q^2) = \frac{1}{2}\sum_i e_i^2 \underbrace{[q_i^{\uparrow}(x,Q^2) - q_i^{\downarrow}(x,Q^2)]}_{\Delta q(x,Q^2)}$$

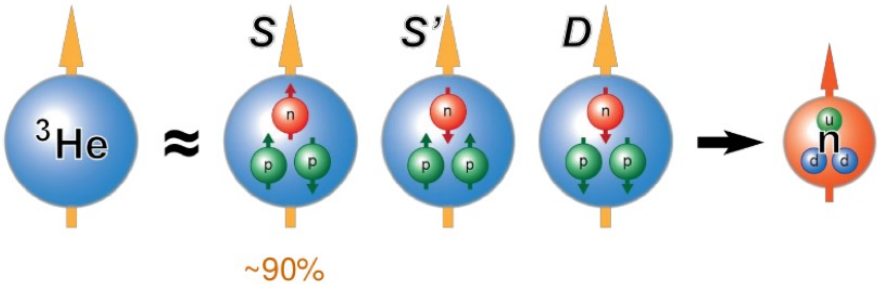
Spin structure function determined from asymmetry measurement

$$A_1(x,Q^2) = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \approx \frac{g_1(x,Q^2)}{F_1(x,Q^2)}$$



Parno et al., Phy Let B DOI: 10.1016/j.physletb.2015.03.067
X. Zheng et al., PRL 92, 012004 (2004); PRC 70, 065207 (2004)

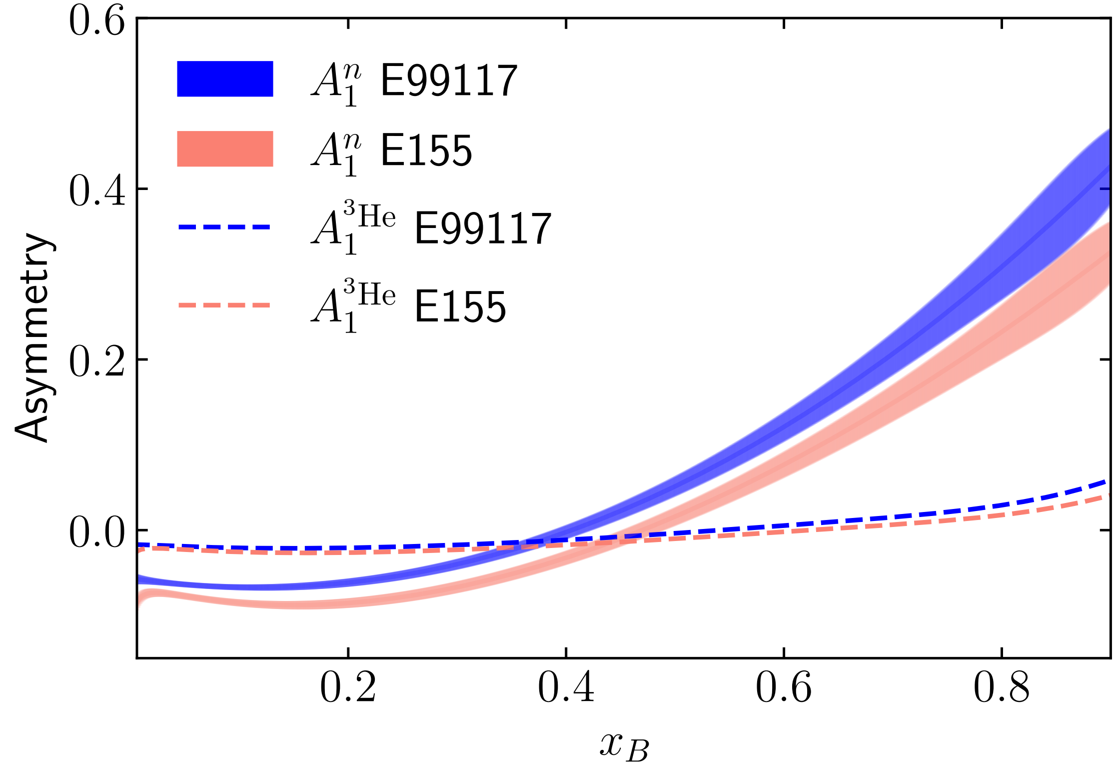
A_1^n is extracted from inclusive DIS e-He3



Neutron pol: Pn ~ 87%
Proton pol: Pp ~ 2.7%

A_1^n is extracted from inclusive DIS e-He3

$$A_1^n \approx \frac{1}{P_n} \frac{F_2^{^3\mathrm{He}}}{F_2^n} \left(A_1^{^3\mathrm{He}} - 2P_p \frac{F_2^p}{F_2^{^3\mathrm{He}}} A_1^p \right)$$



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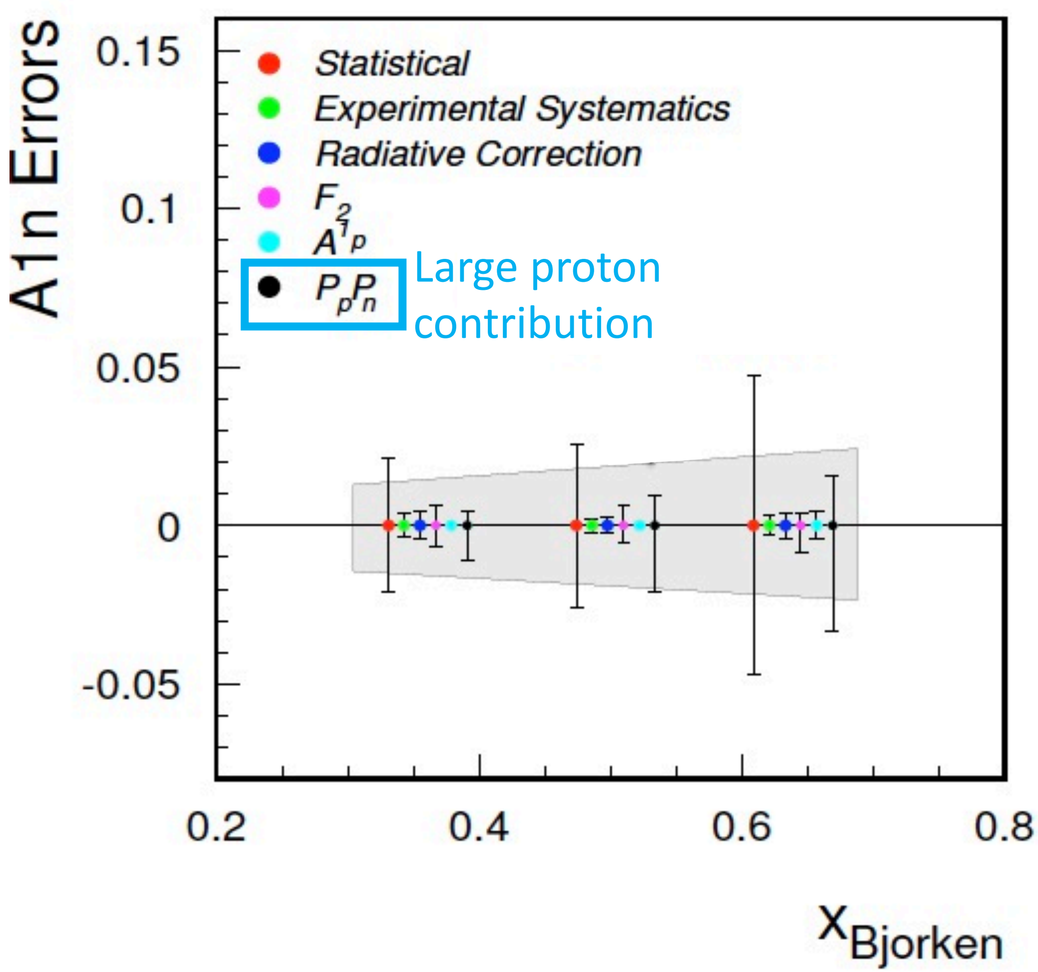
Large model dependence

Inclusive extraction has large systematic uncertainties



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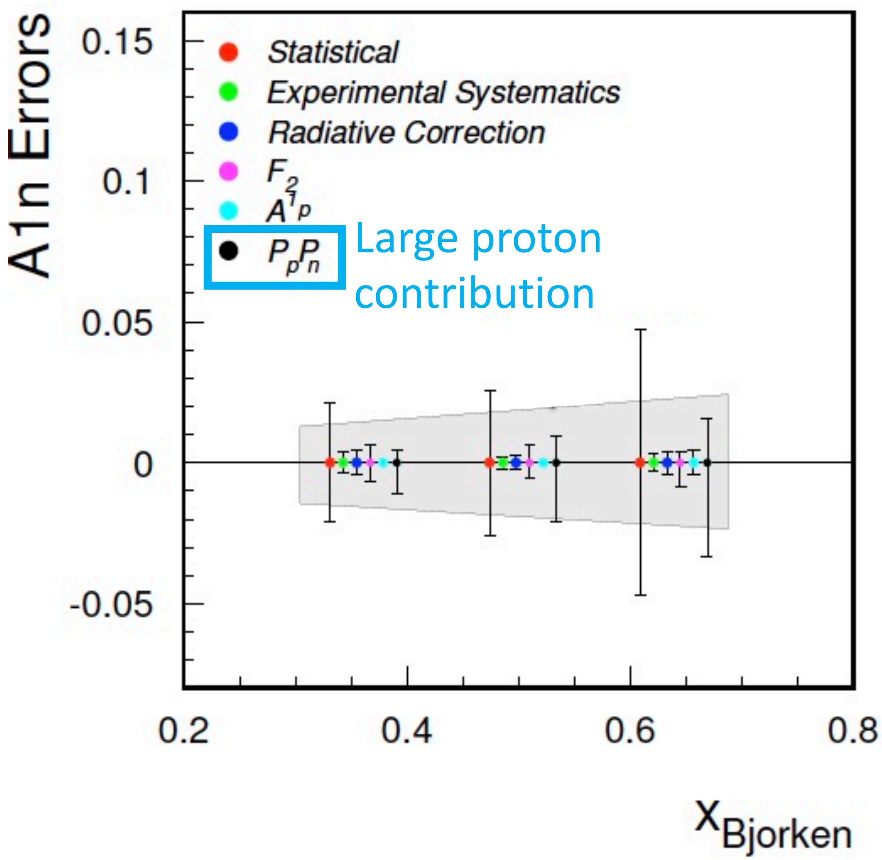
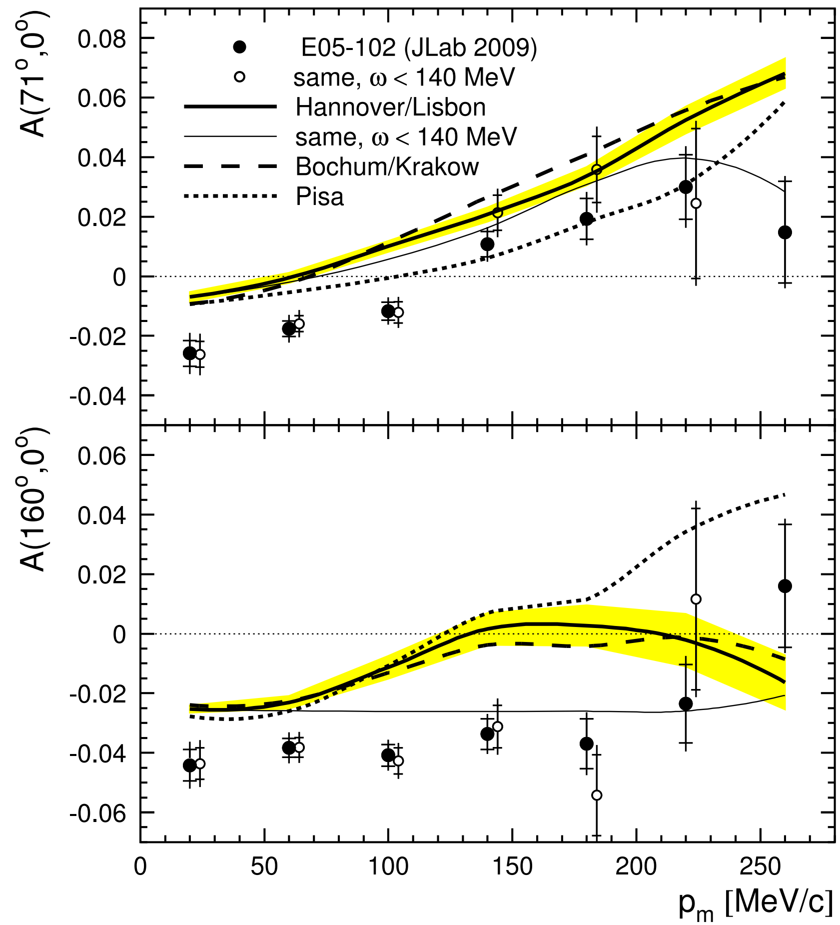
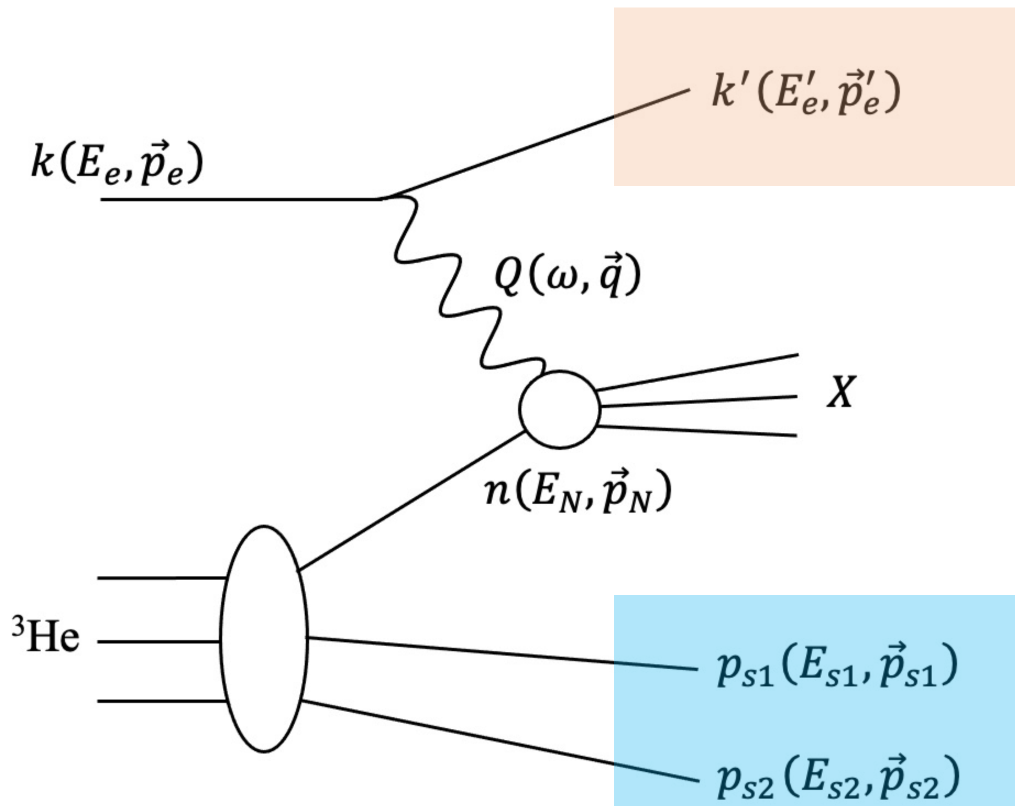


PRL 113, 232505 (2014)

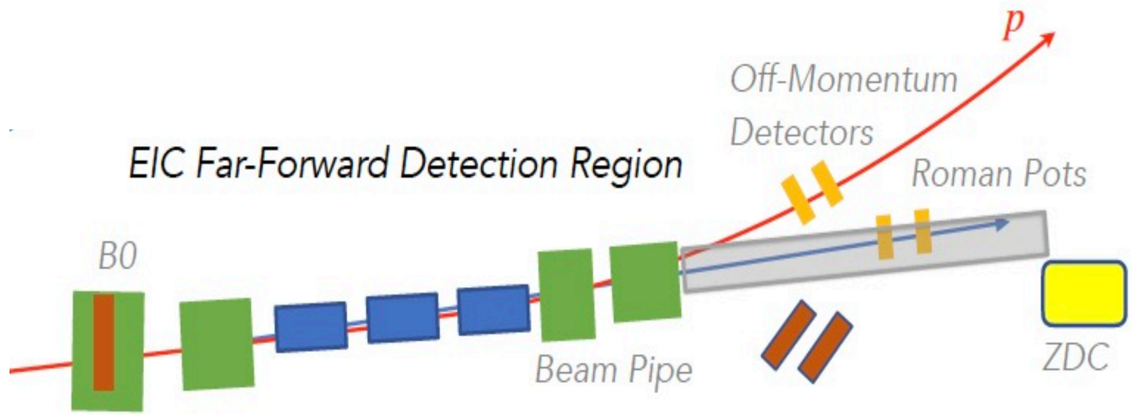


Double spectator tagging suppress model dependence



- ❑ Select the active nucleon in the reaction and break up channel
- ❑ Suppress the contribution of non-nucleonic degree of freedom
- ❑ "Effective" free neutron target

Spectator protons @ EIC Far forward region



- ❑ Magnetic field separates proton from Ion beam
- ❑ Proton: B0 tracker, Off-Momentum detector and Roman pots

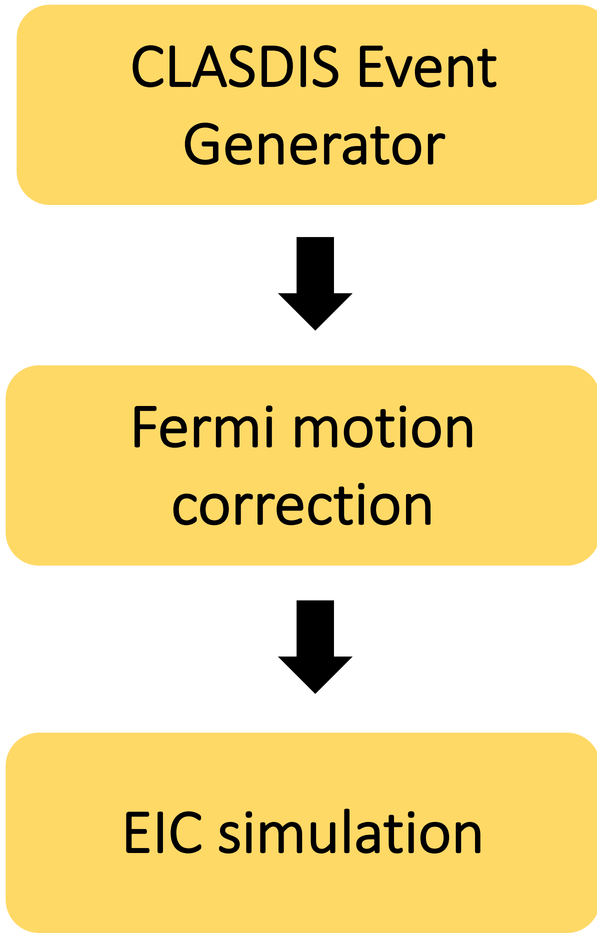
Yellow report section: 11.6
arXiv: 2103.05419v2

Event generator and processing

Existing code assumes standing nucleons.

Add ^{3}He light-front wave function effects (fermi motion)

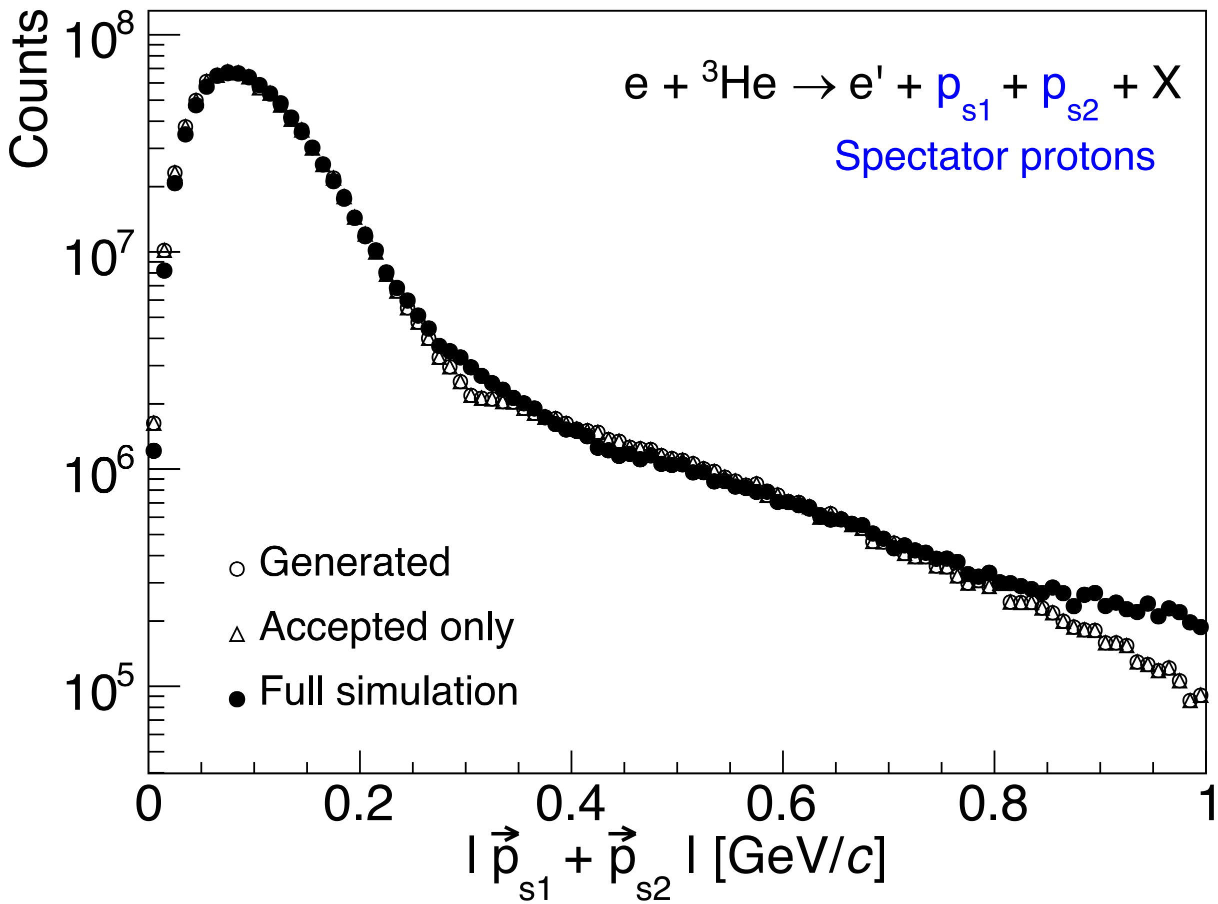
Produce pseudo-data and run via EIC Simulation



arXiv: 2103.05419v2
arXiv: 2106.08805

Spectator momentum at the Ion Rest Frame

eN: 5x41



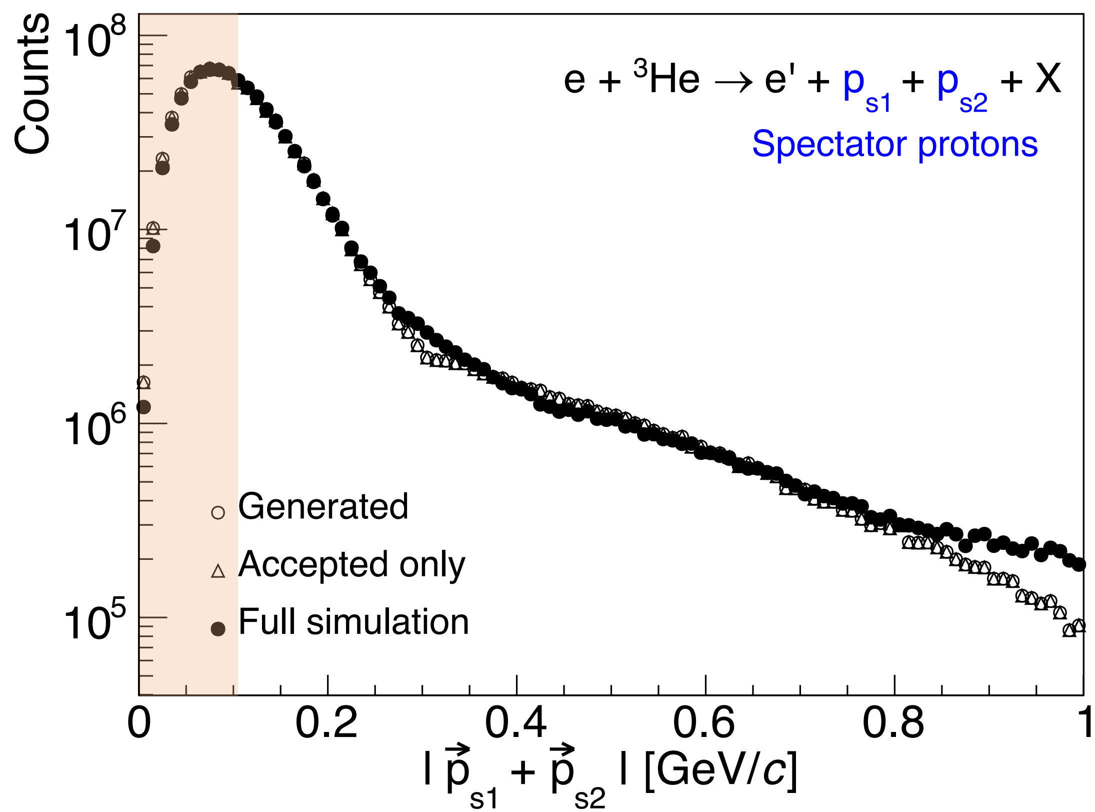
Spectator momentum at the Ion Rest Frame

eN: 5x41

- Spectator protons
  = DIS off neutron

- low total spectator momentum
  = Effective "free neutron" target

- Minimal nuclear effects



Event selection

DIS Selection:

- $Q^2 > 2$ (GeV/c)^2
- $W^2 > 4$ (GeV/c)^2
- $0.05 < y < 0.95$

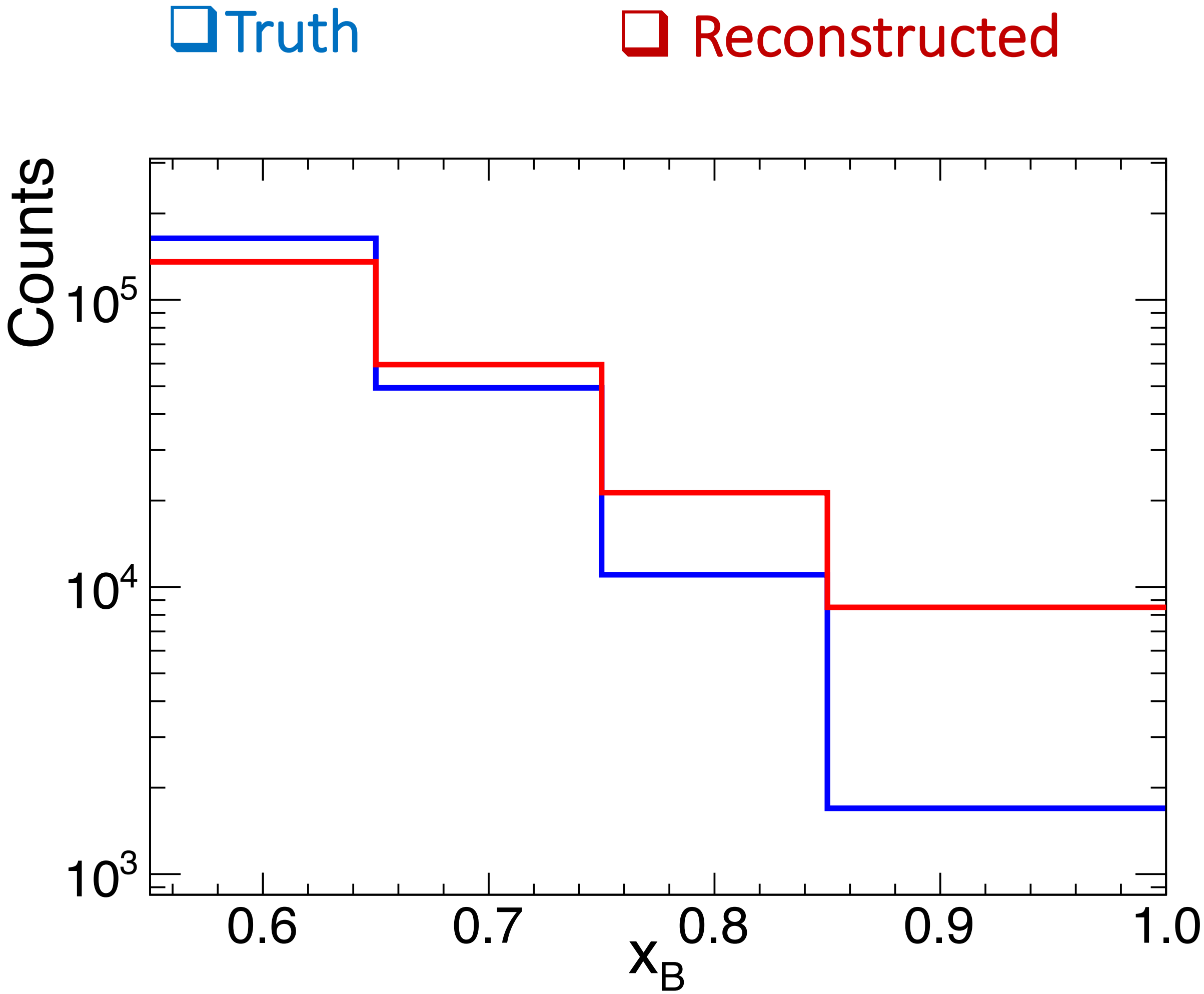
+Tagging :

- Both spectator protons detected.
- $|p1 + p2| < 0.1$ GeV

- ❑ Bin in x & Q^2
- ❑ scale to 1 EIC year (10 fm^{-1})

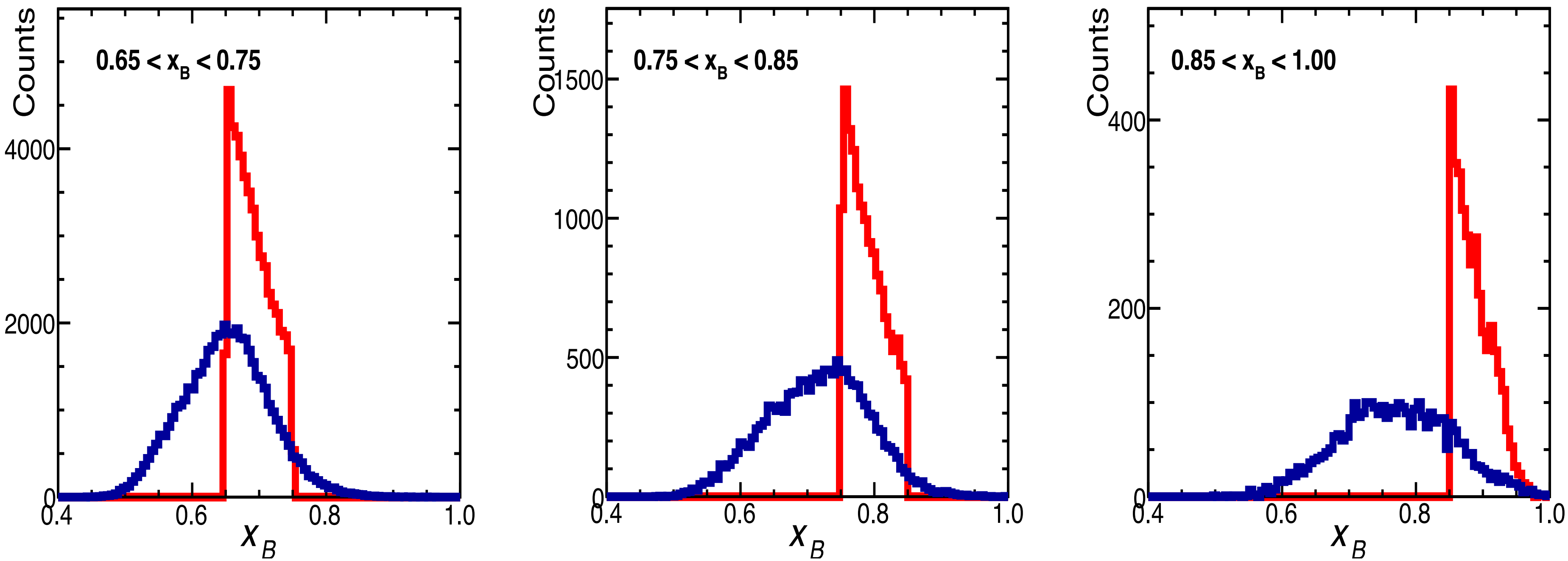
Uncertainty = $\dfrac{1}{\sqrt{N} \;\; P_e \, P_N}$

Large smearing @ high-x



Large smearing @ high-x

❑ Truth   ❑ Reconstructed

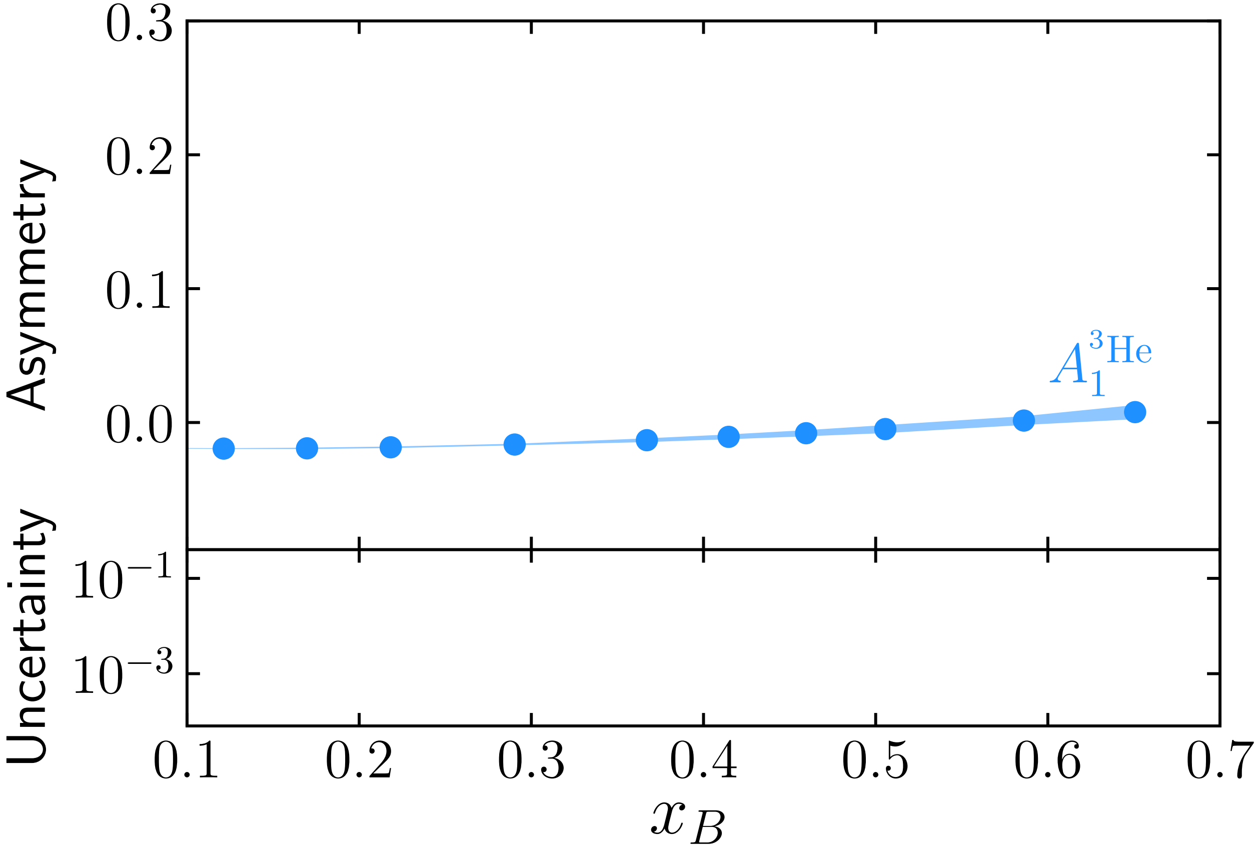


$A_1^{^3\mathrm{He}}$ prediction

$$A_1^{^3\mathrm{He}} = P_n \frac{F_2^n}{F_2^{^3\mathrm{He}}} A_1^n + 2P_p \frac{F_2^p}{F_2^{^3\mathrm{He}}} A_1^p$$

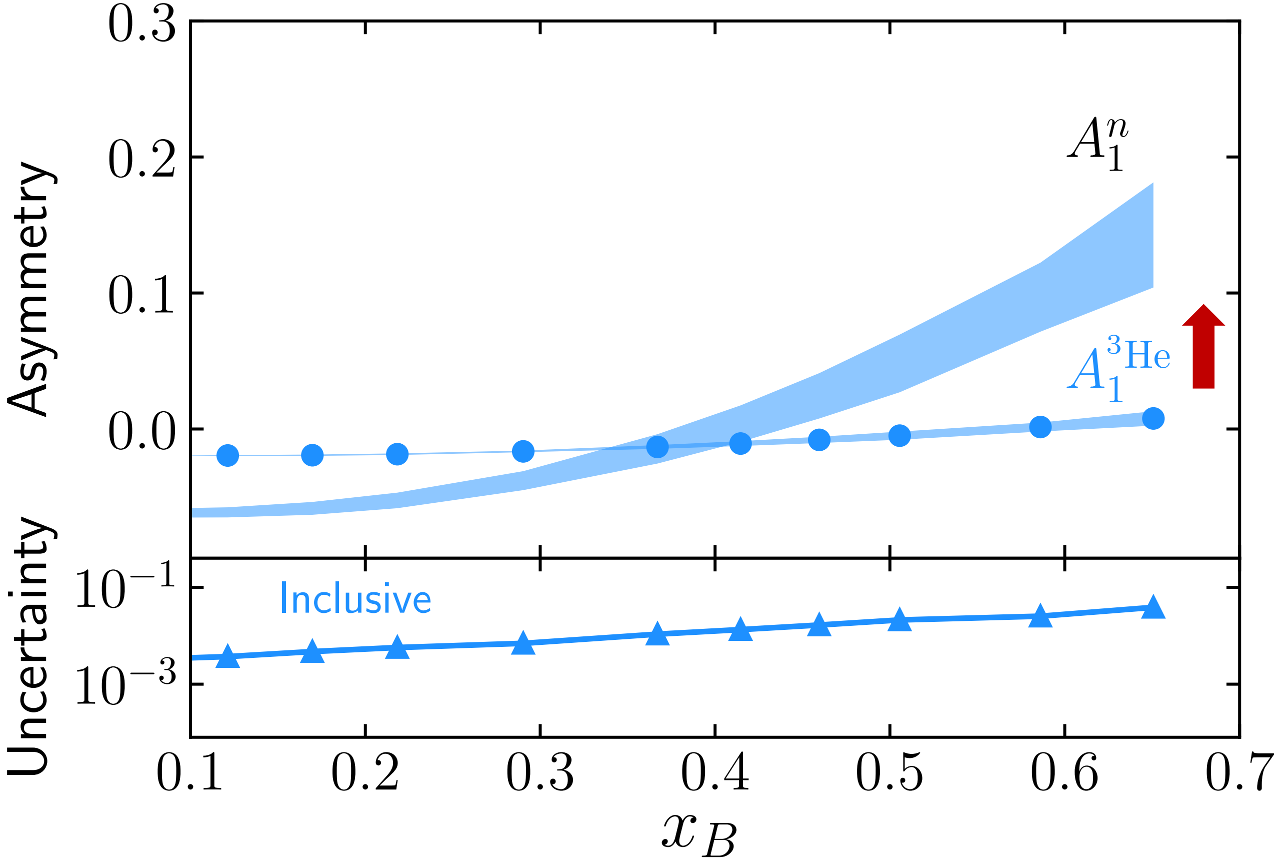
- A_1^n, A_1^p : E99117 fit
- F_2^p, F_2^D : E155 fit
- $F_2^n = F_2^D - F_2^p$; $F_2^{3\mathrm{He}} = F_2^D + F_2^p$
- $P_n = 0.86 \pm 0.02$; $P_p = -0.028 \pm 0.004$

$A_1^{^3\text{He}}$ from 3He(e, e′)



- $A_1^{^3\text{He}}$: Only includes the statistic uncertainty

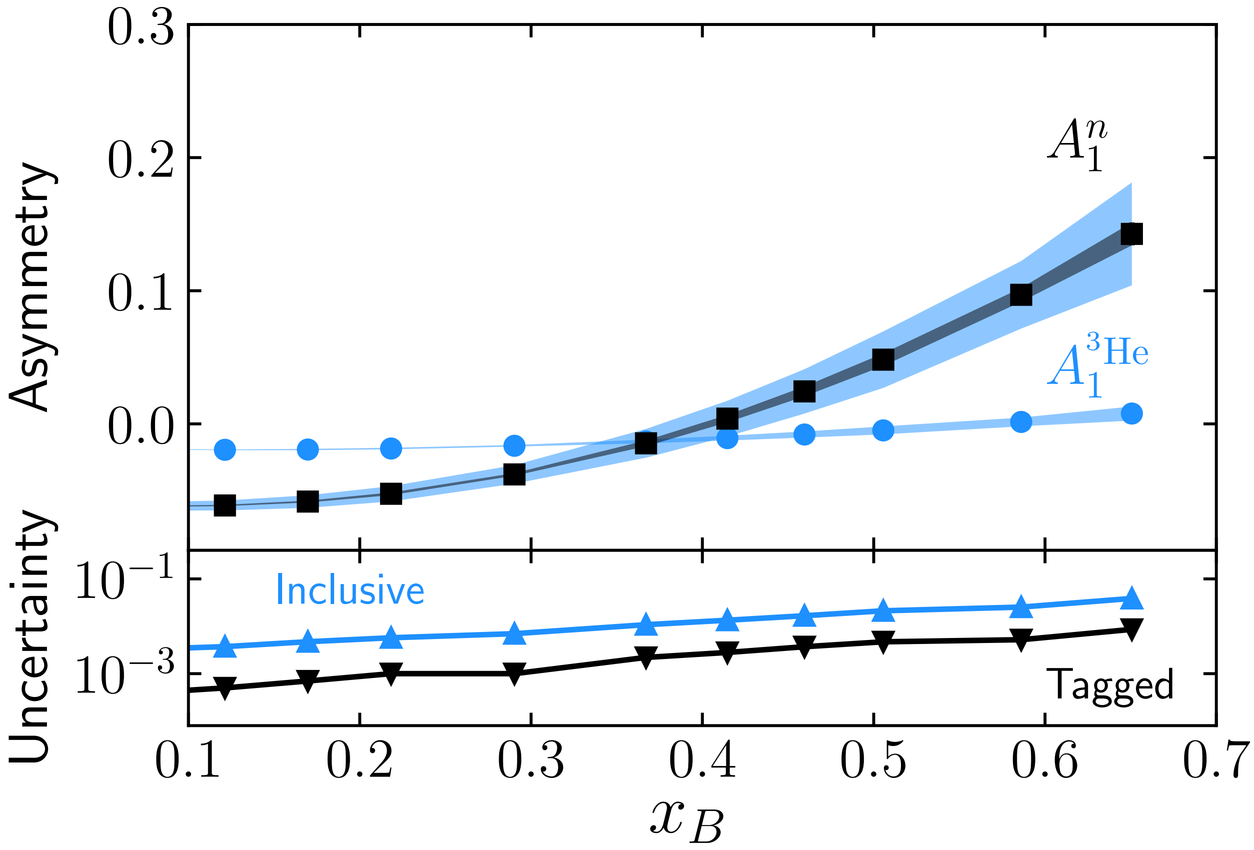
A_1^n from 3He(e, e′)



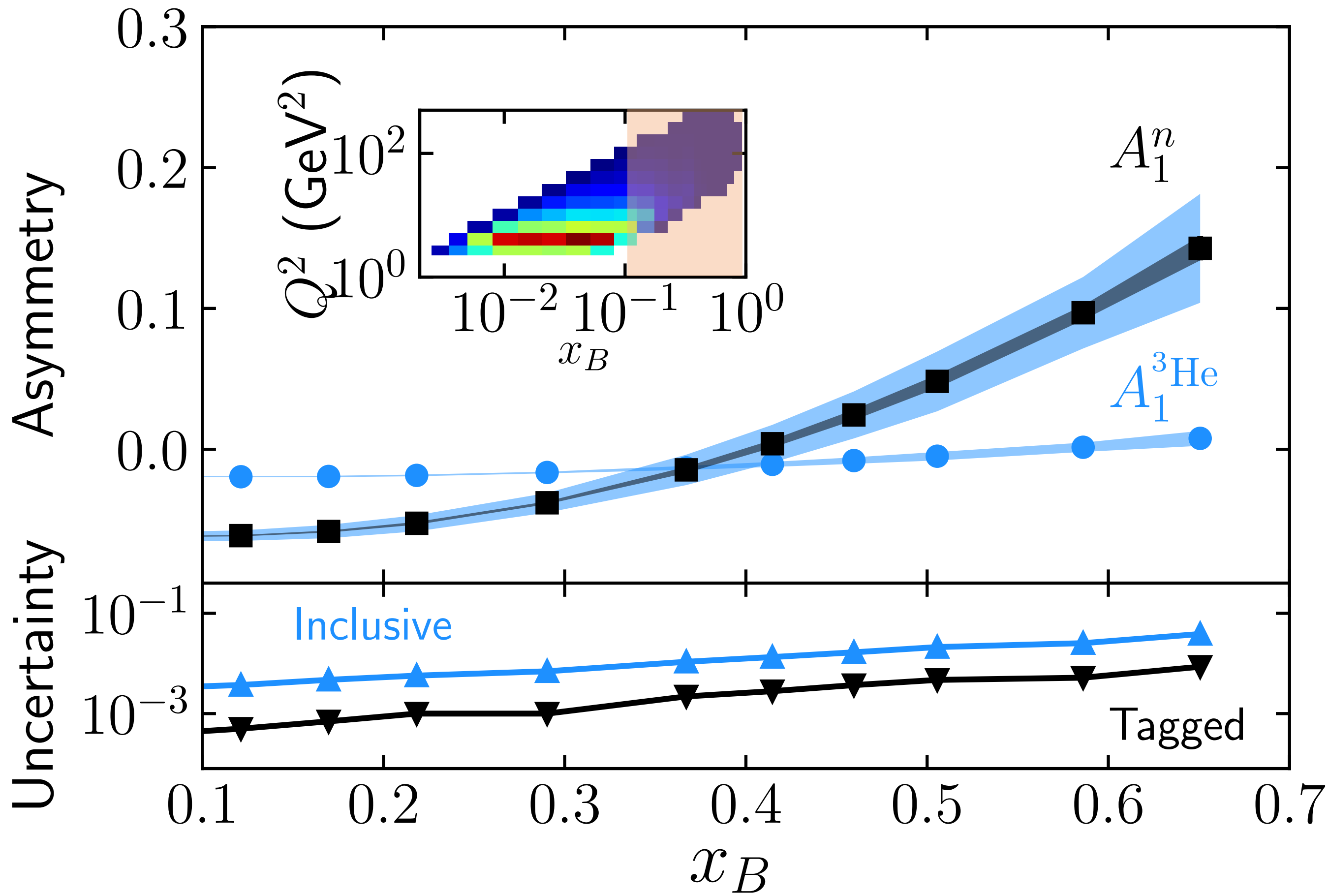
❑ Extraction introduce a large systematic uncertainty

$$A_1^n \approx \frac{1}{P_n}\frac{F_2^{^3\mathrm{He}}}{F_2^n}\left(A_1^{^3He} - 2P_p\frac{F_2^p}{F_2^{^3He}}A_1^p\right)$$

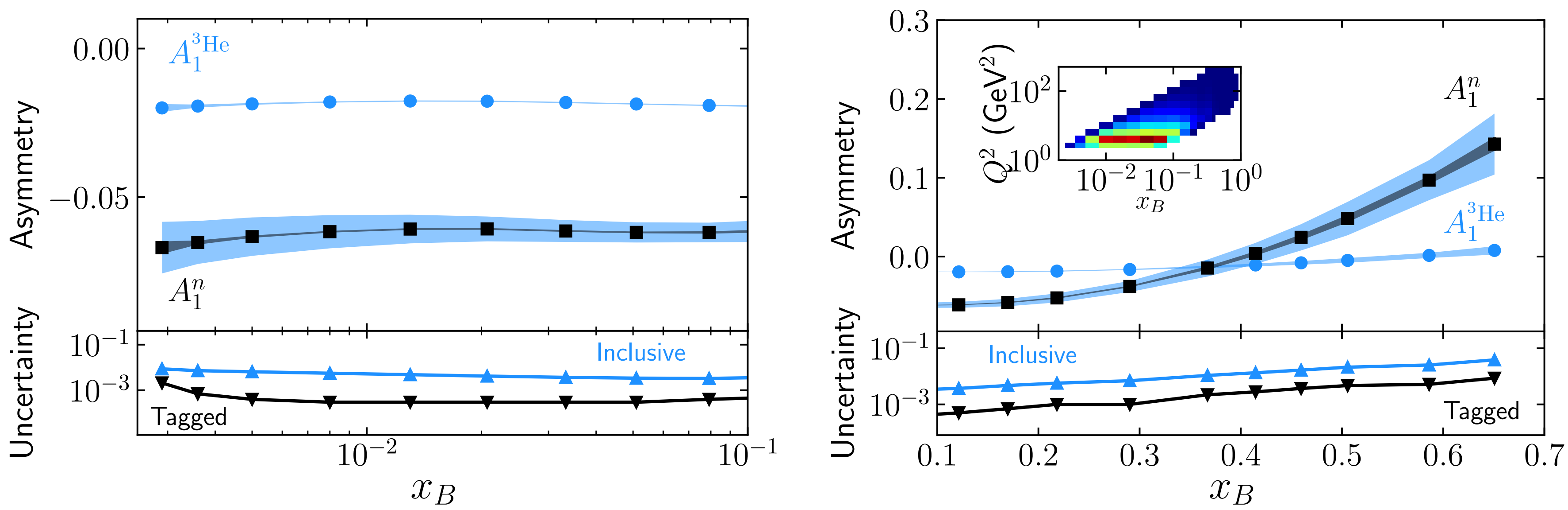
Double Tagging Reduce A_1^n Uncertianty



+ Valence-region Overlap \w JLab12 @ higher-Q^2



A_1^n: Also cover low-x



- Double tagging @ EIC cover 0.003 < x < 0.651
- Significantly reduced model dependent uncertainty compare \w (e,e'): x10 @ x < 0.1 ; x4 @ x > 0.1

Neutron Spin Structure from e-^{3}He Scattering with Double Spectator Tagging at the Electron-Ion Collider

I. Friščić[a,b,1], D. Nguyen[a,b,1], J.R. Pybus[a,b], A. Jentsch[c], E.P. Segarra[a], M.D. Baker[d], O. Hen[a], D.W. Higinbotham[b], R. Milner[a], A.S. Tadepalli[b], Z. Tu[c], J. Rittenhouse West[b,e]

Conclusions

- EIC capable of double spectator tagging
- Minimize the model dependence for neutron spin structure
- Large coverage range of $0.003 < x < 0.651$
- High-x reach limited by resolution

Many thanks to:

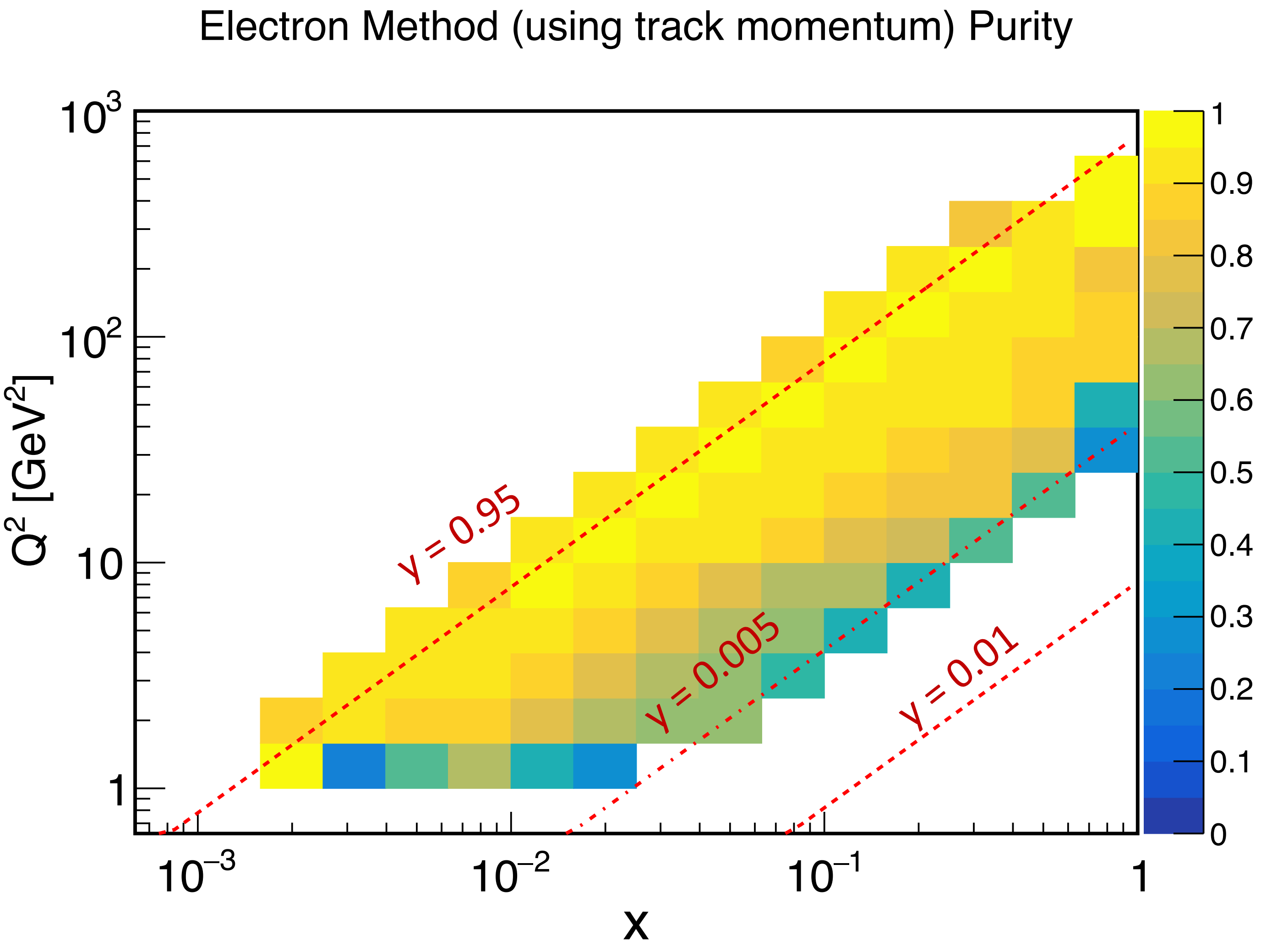
JLab EIC Center & N. Isgur Fellowship

EIC YR Diffraction & Tagging working group

Xiaochao Zheng, Harut Avakian, Barak Schmookler for valuable discussions and suggestions

Back up slides

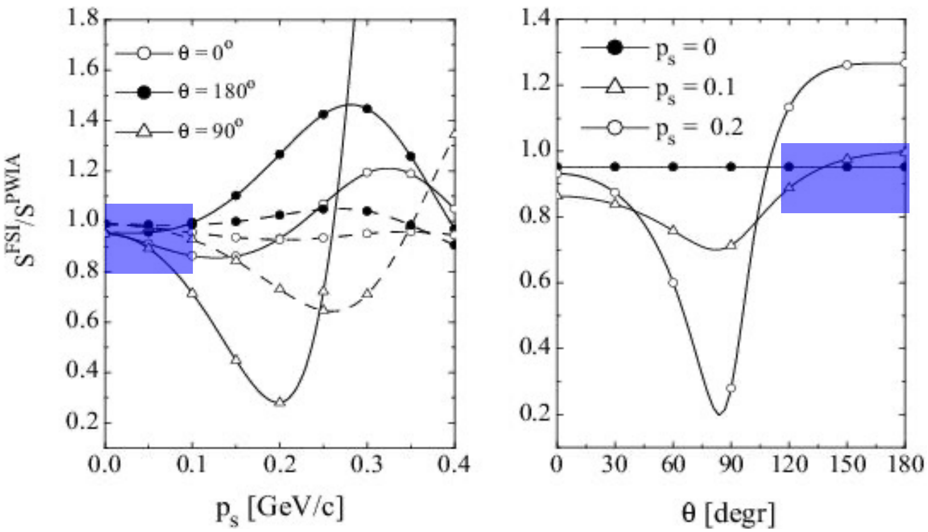
Purity of reconstruction only uses the electron momentum information

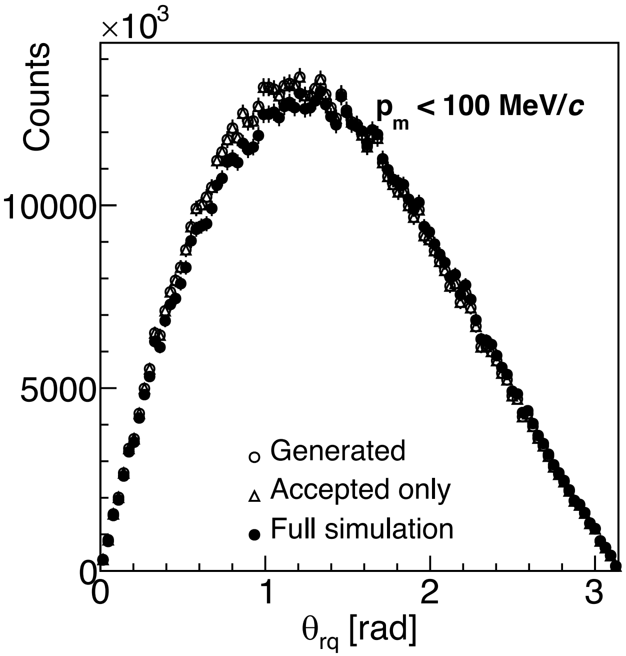


Angle distribution: θ_{rq}: FSI

eN: 5x41

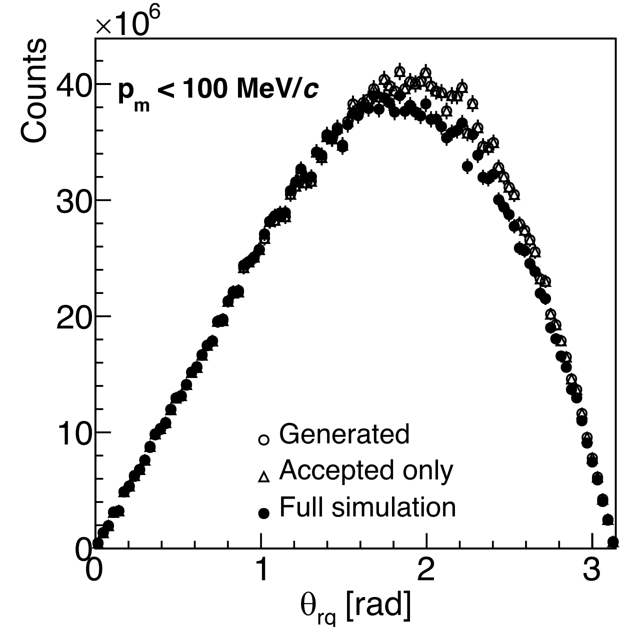
Ciofi degli Atti and Kopeliovich, Eur. Phys. J. A17(2003)133





Talks: Weiss, Wim, Kuhn

eN: 18x110



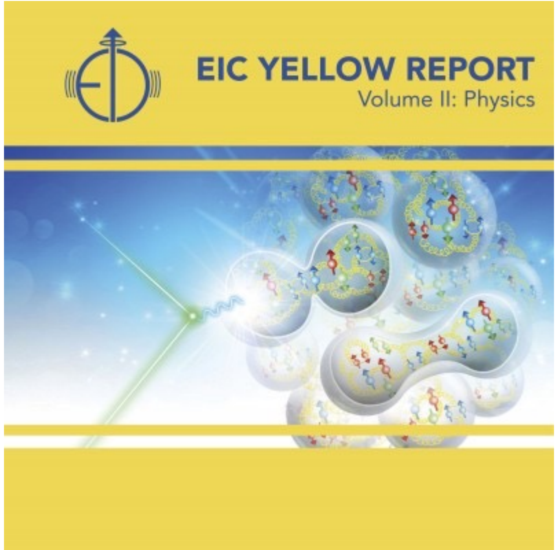
Event generator and processing

Generator:

- CLASDIS for inclusive and SIDIS based on PEPSI
- Unpolarized and polarized PDFs
- Generate event at fixed target frame
- No nuclear effect

➡ Boosted to collide frame

Section: 7.3.8



Fermi-correction:

- Using the light-cone spectral function
- Adding the motion of active nucleon
- Determine kinematic of spectators
- 2BBU, 3BBU, SRCs

EIC simulation: EIC smear and EIC root

- Acceptance and resolution

Many Many thanks to: A. Harut, I. Ivica, J. R. Pybus, E. P. Segarra, A. Jentsch, M. Baker, Or Hen, D. Higinbotham, Zhoudunming Tu, A.S. Tadepalli.